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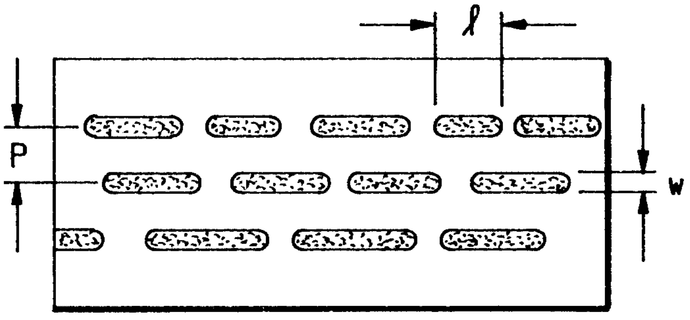
(54) Title: OPTICAL MEMORY SYSTEM FOR INFORMATION RETRIEVAL FROM FLUORESCENT MULTILAYER OPTICAL CLEAR CARD OF THE ROM-TYPE



(57) Abstract: A multilayer fluorescent optical storage medium has data layers with fluorescent pits for storing the information. The pits on each of the layers are organized to define a plurality of stills. Each stack of stills can be read without lateral movement of the reading head. An eight-to-ten code for encoding information to be stored is also used.

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OPTICAL MEMORY SYSTEM for INFORMATION RETRIEVAL from FLUORESCENT MULTILAYER OPTICAL CLEAR CARD OF THE ROM-TYPE.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention is related to an optical memory system for page-by-page retrieval of information and to an optical memory system and a device for information retrieval from fluorescent multilayer Read Only Memory (ROM) optical clear cards, in particular.

Description of the prior art

The existing optical memory systems utilize two-dimensional data carriers with one and two information layers. Most of the previous technical solutions in the optical data recording process propose registration of the changes in reflected laser radiation intensity in local regions (pits) of the information layer. These changes could be caused by interference effect on the relief optical discs of the CD or DVD ROM-type, by burning holes in the metal film, dye bleaching, local melting of polycarbonate in widely used CD-R systems, by change of reflection coefficient in the phase-change systems, etc. [Bouwhuis G. et al, "Principles of Optical Disc Systems", Philips Research Laboratories, Eindhoven, Adam Hilger, Ltd., Bristol and Boston].

Figure 1 shows schematic geometry of two-dimensional space distribution of information pits along the surface of the CD- and DVD-format optical information carrier that uses the 14-bit EFM (eight-to-fourteen modulation) channel modulation pitch. Their space distribution in the CD and DVD-ROM can be characterized with such parameters as typical pit sizes (the shortest pit length – l, width – w, depth – d, track pitch – p) and channel bit length.

See Table 1 for numerical values of these and other parameters of the CD and DVD-ROM [Information Storage Materials, pp. 36, 42].

Table 1. From CD to DVD

Parameter	CD	DVD
Wavelength λ, nm	780	650
Numerical aperture NA	0.45	0.60
Shortest pit length, nm	831	399
Depth, μm	0.13 – 0.15	0.11 – 0.12
Track pitch, μm	1.6	0.74
Channel bit length, nm	277	133
Modulation code*	EFM	EFM**
Physical bit density,	106	508
Mbit/cm^2	1,2	4.0
Reference velocity CLV,	0.9	0.55
m/s	0.65	4.7
Spot size λ/2NA, mm		
Capacity, GB		

* For EFM one has 17 channel bits (14 modulation and 3 verging bits) for 8 data bits. Each channel bit corresponds to 1/3 of the minimum mark length. Physical bit density equals 1/(track pitch x channel bit length x 17/8). For EFM** the 17/8 factor is replaced with 16/8.

So, as you can see from Table 1, switching over to the DVD-format will considerably increase density and – consequently – the amount of stored information as well as reading speed. However, Figure 1 and Table 1 also demonstrate that information pits occupy only part of the information layer, which considerably decreases the density and the amount of stored information in comparison with their maximum limits.

To increase the density of recording one can use such methods as employing emission sources with shorter wavelength in combination with high aperture NA lens (see Table 1 for example [I. Ichimura et al, SPIE, 3864, 228)]. We can also reduce track pitch and increase the groove depth of the land groove recording optical disk [S. Morita et al, SPIE, 3109, 167]. New media and reading methods [T. Vo-Diny et al, SPIE, 3401, 284], pit-depth modulation [S. Spielman et al, SPIE, 3109, 98], and optical discs with square information pits arranged in symmetrical patterns [Satoh et al, U.S. Pat. #5,572,508] are used for high density information storage.

In U.S. Pat. ##4,634,850 and 4,786,792 (Drexler Technology Corp.) to increase data density and also to minimize error one can use a "quad-density" or "micro-chessboard" format of digital optical data, which is read by a CCD photodetector array to quadruple the amount of digital data that can be stored optically on motion picture film (or optical memory cards).

Three-dimensional (homogeneous) photosensitive media that display various photophysics or photochemical non-linear effects in two-photon absorption allow us to achieve data writing density that exceeds several terabits per cubic centimeter. In these three-dimensional WORM or WER data carriers the cooperative two-photon absorption by photosensitive components and by photoreaction products through the intermediate virtual level or registration of refraction parameter changes constitute the most optimal writing and reading modes. This is also true of cases of photochrome [D. Parthenopoulos et al, Science, 1989, 245, 843] or photobleaching materials, and photorefractive crystals [Y. Kawata et al, Opt. Lett. 1998, 23,756] or polymers and photopolymers [R. Borisov et al, Appl. Phys., 1998, B67, 1].

In principle, this writing and reading mode allows local registration of data in the form of pits (similar to information pits in traditional reflecting CD or DVD-ROMs) with changed optical properties within the data medium.

However, actual implementation of this principle constitutes a big challenge due to the high cost and big size of phemtosecond laser sources of emission that are required for this type of recording and also due to extremely low photosensitivity of the media. As a rule, this extremely low photosensitivity of the media is caused by extremely low two-photon absorption cross-section parameters of photosensitive materials that are currently known to us.

Technologically, if we want to increase the stored data amount we should use multilayer two-sided optical information carriers, as they are more efficient. However, their application also has certain restrictions and may create additional problems regarding the design and properties of the data carrier medium and data reading modes and devices, particularly in the writing mode for the **WORM**- and **WER** - optical memory data, especially deep inside the medium.

In a reflection mode each information layer of the multilayer optical information carrier will be coated with a partly reflective coating. It reduces the intensity of both reading and reflected information beams due to its passing through the media to the given information layer and back to the receiver.

In addition, due to their coherent nature, both passing beams are subject to diffraction that is hard to estimate and also to interference distortions of the fragments (pits and grooves) of the information layers.

That is why multilayer fluorescent optical information carriers with fluorescent reading are preferable as they are free of partly reflective coatings. In this case diffraction and interference distortions will be much less due to non-coherent nature of fluorescent radiation, its longer wavelength in comparison to the reading laser wavelength, and the transparency and homogeneity (similar reflective indexes of different layers) of the optical media towards laser and fluorescent radiation. Thus, multilayer fluorescent carriers have some advantages in comparison to reflective optical memory.

The system is based on incoherent signals such as fluorescence, and luminescence has twice as high spatial resolution coherent methods, such as reflection, absorption or refraction (see Wilson T., Shepard C. Theoty and Practice of Scanning Optical Microscopy, Academic Press, London, 1984). Using an incoherent signal allows the multilayer optical memory to increase information capacity as much as eight times.

In U.S. Pat. # 4,202,491 a fluorescent ink layer is used whose data spots emit infrared radiation.

Patent JP # 63,195,838 proposes a WORM disc with a fluorescent reading mode where a data carrying layer was applied to the matted surface of the substratum. It is absolutely impossible to create multilayer information structures on the basis if the WORM discs due to strong optical dispersion of writing and reading emission. However, it is possible to create multilayer optical discs using fluorescent composites. This technology was described in U.S. Pat # # 6,027,855 and 5,945,252, and also in EP 00963571A1.

US Patents # 6,009,065 and # 6,071,671 (V. Glushko and B. Levich) describe devices for bit-by-bit reading of information from multilayer fluorescent optical discs.

This invention is related to fluorescent multilayer Read-Only Memory (ROM) optical clear card. In this invention embodiment data is stored in a multilayer structure consisting of multiple optically thin information layers, which are separated by isolating layers. The data bits are stored in the information layers as individual fluorescent material marks.

SUMMARY

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1. Schematic idea of geometry of two-dimensional spatial distribution of information pits along the surface of the optical data carrier of the CD- and DVD-format, recorded with the help of fluorescent substance by the EFM code.

Fig. 2. Schematic idea of one of the structure options using the ROM-type fluorescent multilayer optical card and its cross-section.

Fig. 3. Schematic idea of the information page (a), zone (b), and frame (still) (c) of the information field of one of the FMLC data layers.

Fig. 4. Schematic idea of geometric configuration of four adjacent information bytes recorded with the help of fluorescent substance by the ETT-code.

Fig. 5. Diagram of the fluorescent multilayer optical card reading device.

Fig. 6. Operational diagram of the optical element and optical card positioning (card moving) system in the reading device.

Fig. 7. Functional sensors that constitute part of the reading device for reading data from the optical multilayer fluorescent card.

Fig. 8. Diagram of the data processing system in the reading mode.

Fig. 9. Optical diagram of the device for reading information from the optical multilayer fluorescent card.

Fig. 10. Schematic idea of top view (a) and cross section (b) of LEDs and microlens fragments of matrixes and microlenses.

Fig. 11. Schematic idea of a microlens matrix.

Fig. 12. Schematic idea of a device for optical card loading and positioning.

Fig. 13. Various ways of adjusting focus from layer to layer that do not require the optical card movement.

Fig. 14. Initial computer image of one of the fragments of the fluorescent optical card written by the EET-code, with $\lambda = 0.65$ mmc and NA = 0.65. This image can be used for manufacturing a photo template to form an information layer of the ROM-type multilayer fluorescent optical card.

Fig. 15. Computer image of the same fragment of the fluorescent optical card information layer that is formed by the reading device optical system positioned along the plane of the CCD-cameras line.

Fig. 16. Computer image of the same fragment that has been read by a CCD-camera, followed by computer processing.

It should be pointed out that the above referenced figures do not reflect the actual scale and dimensions of some elements. Their purpose is just to make it easier to understand the structure and operational principles of the multilayer fluorescent memory system of the ROM-type.

DESCRIPTION OF PREFERRED EMBODIMENTS

See below the description of one of the options of the structure of the read-only fluorescent multilayer optical memory Clear Card (FMC- ROM) 200 and its cross-section. The structure is comprised of the following basic components: a metal or plastic card case (201) that looks like a rectangular parallelepiped, whose dimensions are 45 mm x 25 mm x 2 mm; a 1.6 mm "optical insert" (202) fabricated on the basis of a multilayer optical data carrier (FMLC) 203 positioned upon a glass pad (substrate) 204 whose dimensions are 35 mm x 15 mm x 1 mm. For the pad material one may use quartz, transparent polymers, for instance polypolycarbonates, polyalkelacrylates, polyciycloolefins and others. Protective layer 205, which is approximately 100 mmc thick, serves to protect the optical data carrying medium from mechanical damage by harmful aggressive environment.

Case 201 of the optical card (200) is designed to protect the edges of the data area FMLC 203 from mechanical tension and soiling. It also helps store and move FMC 200 card in the reading device.

Optical insert 202 with a multilayer optical data carrier (203) is attached to the "set frame" 206 of the optical card (200) case (201). This can be done with the help of thermal or photopolimerizing glue that fills the space 207 between the optical insert and the frame (206). Prior to gluing both these parts they should be positioned against each other using "matching notches" 208 and 209 and then exposed to thermal or ultraviolet (UV) radiation for the glue to set.

The fluorescent multilayer optical data carrier (203) is comprised of numerous data layers, so it looks like a stack of 12 mm x 32 mm layers (210) that are approximately 0.5 mm thick (preferably). The dimensions of their operating area are 10 mm by 30 mm and the area contains numerous individual information marks or pits that are similar to reflecting pits used in the well-known CD or DVD ROM systems. These pits may bee seen as fluorescent marks (211) positioned against a non-fluorescent background (212). It should be pointed out that the dimensions of the "information carrying field" 213 (the operational area) in each data layer (210) are approximately 1 mm smaller than the FMLC card (200) dimensions. The data layers (210) are divided by 50 mmc thick "intermediate layers" (219). The intermediate layers are transparent for reading and data carrying fluorescent emission. The stack of data layers (210) and intermediate layers (219) is glued together with the help of photo- or thermal glue layers that are a few microns thick. The entire structure forms a single fluorescent multilayer carrier FMLC 203. To eliminate parasite effect caused by light reflection, scattering and diffraction emitted by the out-of-focus layers we should select similar refraction parameters of both data layers and intermediary layers, if it is possible.

Thus, this FMLC multilayer structure (203) where data layers are interspersed with intermediary layers should include at least more than two data layers (210), though ideally 10 will be better. This structure is positioned upon a pad (substrate) 204. The pad (204) is fabricated from transparent or non-transparent non-organic materials (like glass) or from polymers (like polycarbonate, polyvinyl chloride, chlorinated polyvinyl chloride, polymethil metacrilate, polystyrenes, acrylic, polyolefine or similar materials, acrylate and epoxy photopolymerized plastics, etc). These materials can be polished, ground and molded easily, for instance, one may use injection molding or injection compression molding or employ UV polymerization of initially liquid monomer or oligomer compositions that are solidified by the photoprocess (2P process) [Bouwhuis G. et al, "Principles of Optical Disc Systems", Adam Hilger Ltd., Bristol and Boston]. These materials are treated until their roughness (asperity) is no worse than Optical Class 14 with possible 2 to 5

Newton ring deviations from the flat plane. Only then we may achieve the required quality of the product mechanical properties. Also, with time the pad should be able to withstand deformation and retain its high planar quality and its different thickness at the given locations. The pad (substrate) 204 serves as a pad for the FMLC 203 that is mounted on it, it also helps to achieve precision positioning of the FMC card (200) within its frame (206). In the event when the reading emission component and the fluorescent signal data registering component of the reading device are located on both sides of the FMC 200, the pad 204 may be transparent or at least include a transparent insert made of optically transparent material, which should be located in the same place where the FMLC (203) data carrying field (213) is located.

To eliminate much movement and to minimize the number of photoreceiving components in the reading mode, and also to retain high speed of reading the entire operating area (information field) 213 is divided into a certain number of pages, for instance into three pages (214) (as it is shown in Fig. 2). This page may be approximately 10 x 10 mm. Distance 218 between the two adjacent data pages h is approximately 200 mmc. These pages (Fig. 3a) look as a set of rectangular or square zones (for instance of twenty-five zones) (315) which may be 2 mm x 2 mm, while the distance between them may be 17.4 mmc along the Y-axis and 3.2 mmc along the X axis. Each of them may contain up to one hundred and seventeen stills (316) (Fig. 3b) but only one hundred and fifteen of them may be data carrying. The still dimensions depend on the reading device design and may be like 204.8 mmc by 153.6 mmc with the distances of 17.4 and 0.8 along the axes, respectively. The zero still (319) serves for precision adjustment (up to 0.1 mmc along the X, Y and Z-axes, with precision up to 10^{-3} radians in angular coordinates).

These stills are divided into clusters (317), whose number may reach up to forty-eight in each still (6 x 8 along the X and Y axes of the optical card (200) information field (213), respectively) (Fig. 3c). The cluster dimensions may be approximately 25.6 by 25.6 mmc, and the distance between them like 1.6 mmc along the Y-axis and 0.8 mmc along the X-axis. One cluster is capable of containing 372 bytes of information (one byte (318) equals 10 pits (321) whose dimensions are 0.4 mmc by 0.4 mmc (Fig. 3d) and it contains about eight bits of information). The cluster size also depends on the encoding algorithm, which serves to eliminate aberrations and distortions. According to one of the algorithms in the process of encoding, a group of 32 bytes will store 24 bytes, while a minimal data quantum will be a group of 32 bytes or 320 pits (if we use ETT encoding (eight-to-ten encoding) which is referenced below). Thus, one cluster should have an N x 320 volume where N is more or equals 1. We need to divide stills into clusters to make them more reliable and achieve faster elimination of the harmful effect of a space low-frequency component on the contrast of "0" and "1" signals. In addition, a still also includes a 15 x 15 mmc support field (320) designed for faster focusing and positioning in the process of still reading.

The FMLC (203) ROM data layers (210) may also include other additional ROM address fields that carry supporting data that may support, for instance, mutual positioning of the reading head and the FMC 200 card against one another.

Several stills located within different data layers one above the other may form a stack of stills or information stack. We may read information from the stack without moving the reading head along the FMLC plane, for this we just need to adjust lens focus from a still within one layer to a still within another layer. The FMLC address fields perform the centering and they may be located, for instance, in the first or the last layer or within each of the FMLC layers.

To ensure minimal cost of the optical system alignment and reading adjustment when reading is done layer by layer within one stack of stills, we should keep the thickness of intermediary layers (the distance between the adjacent data layers) at 1 mm and the precision of space overlap of information fields should be within +- 1mm, while the precision of their angle overlap should be about 10^{13} radians.

See Figure 4 for schematic geometry of two-dimensional space distribution of information pits presented as four adjacent bytes (40), recorded with the help of the proposed ETT (eight-to-ten) code of two-dimensional encoding along the surface of the FMLC data layers, rather that the EFM (eight-to-fourteen modulation) 14-channel modulation code that is not used at present. In addition, in the proposed invention one information byte is recorded in the field (microarea) 41 consisting of ten (2 x 5) square cells (let us call it a "2 x 5 field") that have certain dimensions like 0.4 x 0.4 mmc and where each of these square cells may or may not contain fluorescent substance. So the very fact of availability or unavailability of fluorescent substance serves as an indicator of presence or absence of an information pit in the field.

Thus, as we record information each of these pits may be filled out, like cell 42 or it may not, like cell 43, with substance that becomes fluorescent when it absorbs reading emission. So, a byte of information will take up a 10S square, that is S = a x a, where "a" is the square of one square cell, while the other "a" is one of the square sides. The adjacent bytes will be positioned across the space abutting to each other, without any gaps as it is depicted in Fig. 4.

All the 256 combinations that comprise an information byte are depicted on the surface of the data layer (210) as fields consisting of ten (2 x 5) square cells, which may be of two kinds. The first 222 combinations are depicted as fields where each square cell (42) has been filled out with some fluorescent substance (information pit or fluorescent mark) and each of these pits has within its (2 x 5) field at least one similar adjacent cell which is positioned either along or across, while each square cell (43) that is not filled out with fluorescent substance also has one such adjacent cell within its field. Let us call this condition as coupling condition. Then we will see that both two upper bytes and the lower left byte (shown in Fig. 4) meet these requirements.

Each of the remaining combinations may be depicted as two mutually complementary fields where the coupling requirement may not be met either in the upper left or in the lower left cells of the (2 x 5) field, (See Fig. 4 for the lower left byte). There are only 52 of these coupling fields, which ensures a certain reserve (back-up) for servicing combinations, as, ordinarily, only 256 combinations that constitute one information byte are required. In the reading mode our device is capable of selecting that field that meets the coupling requirement within each strip consisting of fields or bytes docked to each other, as the selected field is "docked" to the field that is located to the left of it. Thus, the minimal area that is filled out with fluorescent substance comprises two adjacent fluorescent components or information pits (fluorescent marks) and, consequently, its dimensions will be a x 2a. The minimal area that is not filled out with fluorescent substance has exactly the same dimensions.

With the proposed ETT technology of two-dimensional information encoding we will be able to fill out the entire area of data layers with fluorescent marks (information pits), without leaving any gaps. This, in its turn, will allow the use of simultaneous reading methods with the help of one- or two-dimensional photodetector array, for instance with the charge-coupled device (CCD) cameras.

See Figure 5 - 8 for the diagrams of the reading device unit (500) with a fluorescent multilayer optical card of the ROM-type (501) and its main components. Thus, the reading device will comprise the following main components:

1) System for rough and precision mutual positioning of the optical card and optical components against each other (510) which, in its turn, includes the following:
    - A node for loading the card with a sub-system rotation mechanism (511);
    - Sensors for indicating the loading angle (701 and 702) (the current card coordinates);
    - End sensors indicating the loading device state ("open - closed") (701) and the availability of the card in the loading unit (601);

- Mechanisms for moving the microlens array (according to the focus or moving the card according to the focus);
- Focusing sensor with optical components (703);
- A device for installing and replacing compensating plates (603);
- A device for moving the field lens to adjust the optical system enlarging coefficient (moves along the optical axis); and
- A subsystem controlling the operating devices (engine drives, etc).

2) System for forming numerous beams of reading emission (520) that includes the following components:
   - Most commonly, a two-dimensional matrix of light emitting cells to lighten certain areas of the optical card;
   - Optical sub-system to form a light field consisting of numerous reading emission beams and ensuring the reading of FMLC information stacks (210) that are positioned right in front of brightening light; and
   - Sub-system for matrix control of luminescent optical cells.

3) Optical system (530), which includes a microlens matrix to form numerous optical channels, whose number equals the number of luminescent optical cells. This system serves to transfer the fragment patterns (stills) from the surface that is being read to the surface of the photo-receiving matrix on a set scale. In addition, the optical system (530) also includes those components that are common for all channels: light filter, field lens and optical equalizer;

4) System for registering information coming from the FMC (Fig. 5 and 8) that includes the following components:
   - Detector based on the matrix photoreceiver sensor (801);
   - Detector controller based on a digital signal processor (802);
   - Programmable converting device for identifying (converting) bits to information pits employed in fluorescent recording (803);
   - Device for decoding the antiaberration code (804);
   - Digital interface to relay data to a microcomputer (805);

- Digital interface to relay data flow to the outward decompressor (806); and
- Controller software to produce feedback signals (807).

5) Microprocessor system to control the device components (560);
6) Power supply unit (570);

For our invention we also supply one of the schematic options (See Fig. 9) of an optical data reading device (optical pickup) that uses the ETT two-dimensional way of encoding data in a fluorescent carrier, which is fabricated as a multilayer optical card (200). This ensures simultaneous high-speed reading of big amounts of data.

Basic components of this optical memory system are as follows:

1) Multilayer carrier of the FMC ROM type - a fluorescent multilayer optical card (910);
2) 920 - reading emission (938) device that includes a lighting device (921) and condensing optics (922) with a special selective light filter (923); and
3) 930 - Unit for registering the information signal (937) that includes a matrix (931) made of high temperature (NA ~ 0.5) aspheric microlenses (932), a set of optical compensating components (933), another spectral selective filter (934), a field lens (935) and a photoreceiving device matrix (936). It should be pointed out that the reading emission device (920) and the unit for registering the information signal (930) are positioned in such a manner that the optical card (910) is between them.

To ensure rearrangement of the optical card layers the card (910) makes a vertical movement. However, there is a second option, which is more preferable. In this option we use a set of special optical compensators. These compensators (933) are thin, optically transparent high precision plates that are as thick as intermediate layers and consist of extensible optical wedges, etc. (See Fig. 13 and [US Pat. # 5,381,401]). They are periodically inserted into the optical channel of the reading device. The number of these optical elements equals the number of data layers in the optical card. We think the second option is more preferable, as in this case we manage to eliminate aberrations caused by modifications of optical density. In the second option the depth of layer rearrangement is restricted only by the optical system operational distance. It is also possible to use adaptive optical elements, for instance, spatial light modulators fabricated from liquid crystals. This option is more promising, as it does not only rearrange focusing but also holds one device in focus automatically (auto focus).

Spectral selective light filter (934) serves to filter remaining reading emission to separate the required signal produced by the data carrier fluorescence (937). It is located between the microlens matrix and the field lens. In another option we may use reflecting spectral filters that are installed in the reading device (in front of the receiving device). These Notch type filters may be rearranged electrically and they are fabricated from liquid crystals that ensure good spectral filtration of emission.

To excite the luminescence of the optical card (910) data layers, the card is lighted by emission, whose specter correlates with the specter of the absorbing strip made of luminophore. Semi-conductor emitters such as **LEDs** (light emitting diodes) serve this purpose very well thanks to their well-known properties. They may be solid, organic or laser diodes (**LD**). To increase the speed of reading data from the optical card and to minimize the card movements we suggest using LED matrix lighters or a LD matrix with vertical cavity surface emitting lasers (**VCSEL**). This device may be fabricated as a set (matrix (921) of individual semiconductor diodes (924) or as a solid structure created by planar technology. Matrix 922 made of microlenses (925) that serves to condense incoming emission also may be fabricated as a set or as a solid structure created by integral technology.

We have selected such a technological solution that employs a symmetrically set matrix (921) made of twenty-five commercial high-brightness blue LEDs (924). These LEDs are manufactured using the **InGaN** heterogeneous structure grown on a sapphire substratum. The diodes were positioned as a square grid (5 x 5 elements) with the distance of 2 mm between the adjacent LEDs. The set microlens matrix (925) had similar dimensions. The dimensions of each light diode were approximately 350 x 350 x 100 mmc. Some diodes had contacts only on one side.

The lighting device (920) included its own matrix (921), LEDs and an electronic controller (not shown in Fig.9) that ensured switching any of LEDs (924) for as long as it was required.

The LEDs crystals were arranged in a strict periodical alignment and positioned on a silicon pad (100) (Fig. 10) that was aligned along the plane [100], which also served as a thermal conductor and, when necessary, reflected the LED emission (101). The system of two-way contacts was fabricated following the standard integral technology by spraying alternating metal and dielectric coatings and using photolithography and chemical staining. To make metal reflectors (103) we used alkaline staining. Alkaline staining substance was used selectively and affected only open square areas, as the rest of the material was covered with a protective SiO_2 mask. The reflector was made in the form of a truncated pyramid, whose facets were positioned at a 55-degree angle in relation to the plate. The reflector inner surface was coated with aluminum. The use of these reflectors ensured a 1.5 increase of outgoing optical power as compared with the option where the device was mounted on a flat metallized silicon surface.

After we used soldering to open the contacts (102), the matrix base (100) was docked with another matrix (104) made of ball-like microlenses (105). The docking was performed with the help of high-precision equipment and the structure was assembled inside an integrated circuit framework whose lid had a band-pass light filter window (923).

The set matrix made of ball-like microlens condensers (922) collected emission coming from each of the LEDs, forming 25 beams, whose emission intensity (RMS < 0.07) was distributed equally along the plane of the optical card data layer that was being read within the boundaries of a data still (approximately 200 x 150 mmc). The LED emission specter may include a weak long- wave wing that may overlap with the luminophor strip of the optical card (910). To eliminate this parasite signal we positioned a band-pass optical filter (for instance, a dichroic mirror) (923) on the matrix outgoing plane.

In the data reading mode the activated LED simultaneously lighted a stack of stills in all the card data layers. Projection of certain pages onto the matrix made of photoreceiving cells was made possible by changing the focus of the receiving microlens (932). The LEDs were activated one after the other in a time sequence. After data reading from 25 stills was completed the optical card was moved along to a page width distance, and the entire process was repeated.

A microlens matrix (931) forms an initial pattern (image) on the indefinite number of data layers. Like the LED matrix (921), the microlens matrix consists of a set of 25 microlenses positioned in a square grid (5 x 5 elements) with the distance of 2 mm between the lens centers (Fig. 11). It is positioned at a distance of about 1 mm from the information field (213) of the optical card (200). As each of the microlenses is designed to relay a fluorescent pattern (image) (fluorescent emission specter band is approximately 50 nm) of a data still that is made of elements that are less than 1 micron (approximately 200 mmc x 200 mmc), we should select such an optical design that would be maximally close to the theoretical limit. The numerical aperture of each of the microlenses is no less than 0.5 at the fluorescent wavelength (about 500 nm). Commercial microlenses used in CD players with a 0.5 numerical aperture and a 5 mm diameter have a 100-mmc field of vision. As they are just elementary lenslets they are not protected from chromatic aberrations. The design option that we propose (which option?)allows us to increase the field of vision up to 200 mmc and to diminish the lens diameter up to 2 mm. In our design we also use a binary (?) surface coating to eliminate chromatic aberrations in the entire fluorescence specter range. So, the basic parameters of each of the microlenses are as follows: achromatic lenslet, operating specter range - 470-520 mmc, diameter - 2 mm, focal distance - 2 mm, numerical aperture - 0.5, enlargement - indefinite.

The field lens (935) serves to project each of fluorescent patterns of the data stills (316) formed with the help of relevant microlenses (932) of the matrix (931). The field lens projects them onto one and the same place on the plane where a photoreceiving cells matrix is located (936). Its diameter somewhat exceeds the information field diameter (213) of the optical card (910) (preferably 1.2 cm) and its preferable focal distance is 40 mm, as it determines optical enlargement of the entire optical system. The ratio between the focal distances of the field lens (934) and a microlens located in Matrix 931 must approach the ratio between the photoreceiving cells matrix (935) and a data page (?). In this operational mode of the optical system the image of any data still which is centered (located along the axis) of each microlens (932) in the matrix (931) will always coincide with the location of the photoreceiving cells matrix (936) (Fig. 9).

As a photoreceiving matrix one can use a CCD CMOS array. Thus, we have used a standard CCD camera that consists of a 1024 pixels array (768). The dimensions of each pixel are 4.65 by 4.65 mmc, while its still frequency is 25 stills per second.

The process of data reading includes the following major phases: loading an optical card into the reading device; installing positional sensors, and data reading.

See Fig. 12 for one of schematic options for loading and positioning an optical card in the reading device. In the first phase a container (1201) with an optical card (1202) is placed next to the docking flange (1203) and is locked in place with a latch (catch) (1204).

A linear (?) device for rough moving (1205) grips the end of the card and moves it into a locking device (1206) of the reading unit. The container exit (1201) and the locking device (1206) opening have funnels (1207) that ensure the smooth motion of the card (without a hitch). Locking device positioning sensors (1208) control the motion of the motion mechanism (1209) and when they sense the marks (notches)(1210) on the optical card frame (1211) the motion stops. The card is held in place by a programmable device.

The moving device constitutes a set of at least 2 three-coordinate piezoceramic devices that ensure low pitch cyclic motion in any of the three directions. A combination of phases and motion directions makes it possible to move the locking device together with the card in a big dynamic motion with high resolution that is equal to several hundreds of micron.

Movement is achieved by supplying voltage to the motion devices. When the devices are in the starting position, then in Phase 1 voltage is supplied to Device 2 and then comes the command "forward and up", and Device 2 receives the command "back and down". In Phase 2 the devices/device that went up are /is now moving vertically to its starting position. Then the cycle repeats itself.

Rotation is ensured by distributing piezoceramic devices along the plane and their movement in the opposite directions.

The optical motion sensor looks like two linear funnels. One of these funnels, which is a movable funnel, is attached to the locking device, while the other (stationary) is attached to the case. When the funnels are exposed to a parallel light beam the image that looks like numerous strips is received by the photoreceiver. A pitch between the strips depends on the funnels' angular alignment, while the position of the strips depends on the funnels' angular shifting. The employment of a PZC slide (ruler) allows measuring the precise position of the strips, while the photoreceivers can count the number of strips that it has passed by and, consequently, the number of funnel periods.

A locking device constitutes a platform with optical card guides (roughly), a clamp and movable components of funnel sensors.

In the reading device pages are lighted by a lighting device to be read. The data page fluorescent image is enlarged and projected onto the matrix surface of the photoreceiving device. The enlargement coefficient is selected in such a manner that one pit from the data page should be projected onto a specific group of pixels, for instance, onto 2 x 2 pixel square. In other words, the positions of pits and pixels are strictly correlated. For instance, a pit in the upper left corner will correlate with 4 pixels in the upper left corner of the photoreceiving matrix. This type of solution (correlation between pits and pixels) helps eliminate costly image processing, it also employs fairly simple and inexpensive microchips for image decoding. The data page decoding algorithm is described below and it includes consecutive polling of the photoreceiver matrix pixels with the following processing of the pixel signals.

<u>Phase 1.</u> Loading the card.

The loading node slides out of the device. The card is inserted into the receiving slot (or receiving tray) of the device until it is locked in place. As soon as the sensor confirms the card availability the loading node will slide into the reading device and stop in a position that correlates to the position of one of the information sections. This loading process should ensure that the adjustment page would be in the field vision of a pre-selected lens of the lens array. The adjustment page is in the data layer and its dimensions are equal to the dimensions of the data page. The adjustment page consists of a number of fluorescent marks (see section that describes the card). The precision of the card initial set-up in the loading device equals half the value of the information page size along each of its coordinates. For example, if the data page size is 200 mmc x 150 mmc the precision of the installation is supposed to be 100 mmc along one coordinate and 75 mmc along the other.

After the card and the node have been roughly installed lighting is switched on. The lighting system channel corresponds to the adjustment page. The electric pulse that switches on the lighting system channel is synchronized with the pulse that starts the photoreceiving device (FRD) still scanning. A fluorescent image is projected onto the FRD matrix surface. Using the fixed image the multilayer fluorescent card registration system forms control signals for the following coordinates: 1) “Focus,” 2) two coordinates in the “X” and “Y” planes of the card, and 3) angular coordinate “ф”. Through the control system these signals are sent to the positioning system. It takes several phases to adjust the card: 1) first, the focus is adjusted; then 2) the card is rotated in its own plane and 3) the card is moved in this plane until it is positioned in such a way that the lines and columns of the adjustment page match the corresponding lines and columns of the FRD matrix (the correlation law will be described when we come to the adjustment page). If some marks on the adjustment page fail to match the FRD corresponding pixels, it means that the optical system magnification is not equal to the nominal one. Magnification adjustment is carried out by small movements of the field lens along the optical axis in relation to the FRD. Using the image of the adjustment page, the multilayer fluorescent card registration system develops the “scale” fault signal and sends it to the device that controls the movement of the field lens.

As soon as all fault signals reach zero, we may assume that the card has reached its precise positioning in its starting position with zero initial coordinates.

Phase 2. Setting up position sensors.

When the precise positioning of the adjustment page is confirmed the loading node position sensors counters and the micro-lens massive sensors counters reach zero. The further positioning of the card continues using the data of the position sensors.

Phase 3. Reading the card.

Using the position sensor data the card is moved to a position that correlates with the first information page and the moving distance is equal to the spacing period of the pages. The lighting system channels are switched on one after the other and the FRD reads data from the information pages.

Then the card moves to its next position, and this process repeats itself until the lens matrix scans all the data pages within the area "in charge of" all the lenses. So, in the course of one positioning cycle it is possible to read many data pages. For example, it is possible to read 25 pages if we select the 5x5 format for the microlens and lighting device matrix. This solution allows to reduce positioning time when a single FRD is used and, consequently, to noticeably increase the speed of the data relay flow.

When the device has competed the reading of the information sector (information sector consists of all data pages in the vision zone of the microlens matrix) the card returns to its initial position, i.e. to a position with zero coordinates according to the readings of the position sensors. The card (or the microlens array) is shifted along the optical axis to a distance that equals the distance between the layers. The procedures that went on in Phases from 1 to 3 repeat themselves in the new layer.

Thus, a major advantage of the optical arrangement described in this document is its ability to read 25 data pages without any mechanical movements. Then the card, as a single unit, is shifted to a distance of 200 mmc, and again it is possible to do the reading without any moving anything else. Data page reading frequency must be synchronized with the operational frequency of the matrix made of photoreceiving components.

Rearrangement along the card layers is carried out either by direct vertical shift of the optical card (910) or by employing optical compensators (933) (thin plates that are as thick as the distance between the layers (121) or stacked extensible wedges (122), etc.) The second method is more preferable because it eliminates aberrations caused by the change of optical thickness, and rearrangement depth along the layers is limited only by operational distance of the optical system. The use of adaptive optical elements, for example, liquid crystal spatial light modulators (123), is also possible. This method looks more promising, as in this option a single device simultaneously carries out two operations: readjusting and maintaining focus (auto-focus).

We need two filters to filtrate the LED emission. One filter is placed between the (Illegible) matrix and the fluorescent card to cut off part of the LEDs emission specter that overlaps with the dye fluorescent specter. The second filter is placed between the microlens matrix and the field lens to filtrate the remaining part of the LED emission produced by data carrier fluorescence. Still other option includes application of electrically adjusted reflecting specter filters of the Notch type based on liquid crystals. They are installed in the reading device (before the photoreceiving device) and do a good job filtrating emission along the specter.

Identification of fluorescent (42) and non-fluorescent (43) square elements (pits) (Fig. 4) in each data layer of the multilayer optical card is carried out in the layer-by-layer mode while the card is moving horizontally under the CCD-cameras line (or when the CCD-cameras line is moving along the card. The motion speed is synchronized with both the value of the channel bit and camera still frequency. In this case you can simultaneously identify pairs of adjacent elements of each vertical column (a bottom element of the upper strip and an upper element of bottom strip in Fig. 4).

If the signals received from certain pixels of the CCD-camera that cover correlating square elements of the fluorescent data layer simultaneously exceed a certain level L_1 , then both elements are read out as information pits. If both signal do not exceed a certain level $L_2 < L_1$, then both elements are not information pits. But when the two above referenced requirements are not met, the element with a stronger signal constitutes an information pit, while the element with a weaker signal does not. The L_1 and L_2 values are set beforehand. They depend on the channel bit length, the ratio between the information pit (fluorescent mark) value and the CCD-camera standard pixel value. They also depend on the reading emission wavelength, the lens numerical aperture and its enlargement coefficient. For this particular reading device these values can be regarded as set.

Let us assume that I_n and I_m are the values of fluorescent signals in the locations where the information pit is present and where it is not available, respectively. It has been proved that identification precision $C = (I_n - I_t) = (I_2 - I_m)$ for the ETT case (two-dimensional method of encoding information) exceeds the corresponding value for the DVD-systems within a wide range of changes of the reading device parameters, and, consequently, the probability of data reading error when reading is performed by a CCD-camera and information is encoded with the ETT code is less, than probability of error when reading is performed by a DVD disk.

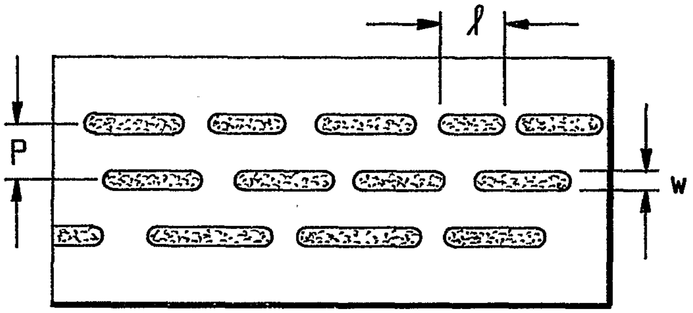
See example in Figures 12 – 14, which present an initial computer image of a data carrying layer fragment of the multilayer fluorescent optical card, written with the EET-code where λ = 0.65 mmc and NA = 0.65 (Fig. 12); its computer image formed by the optical reading device in the plane of the CCD cameras line (Fig. 13) and the actual image of the same fragment read by a CCD camera. The subsequent processing of the last image will allow us to restore the initial image of this fragment, while probability will equal 1 (Fig. 14).

What is claimed is:

1. A multilayer fluorescent optical storage medium comprising:
a plurality of data layers; and
on each of the plurality of data layers, a plurality of fluorescent pits;
wherein the pits on each of the layers are organized to define a plurality of stills.

2. A method of recording information in the medium of claim 1, wherein information is recorded in the medium in an eight-to-ten code.

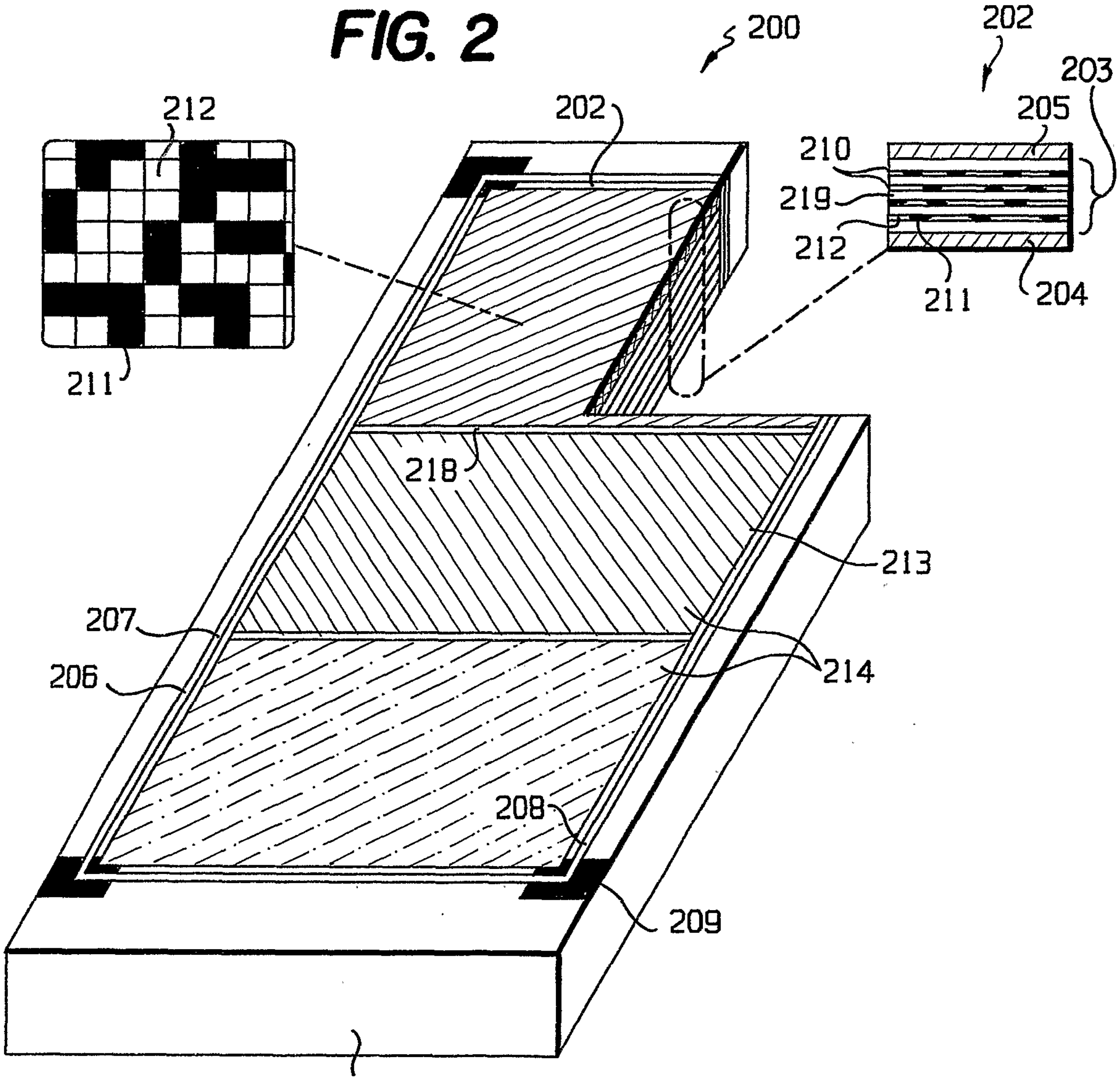
3. A method of reproducing information from the medium of claim 1, wherein corresponding stills on the plurality of data layers define stacks of stills, and wherein the information in each stack of stills is read without moving a reading head parallel to a plane of the medium by changing a focus of the reading head.



l
P
w

FIG. 1

FIG. 2



200
202
203
205
210
219
212
211
204
212
202
211
218
213
207
206
214
208
209
201

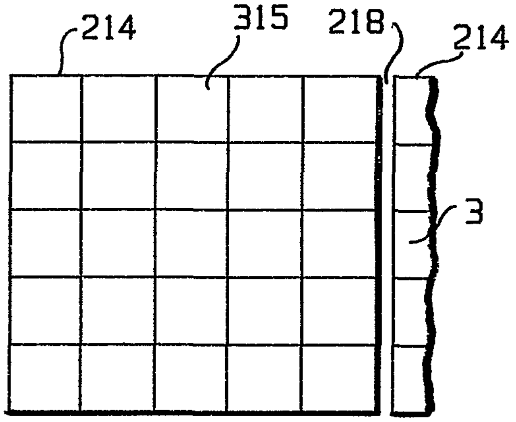


FIG. 3a

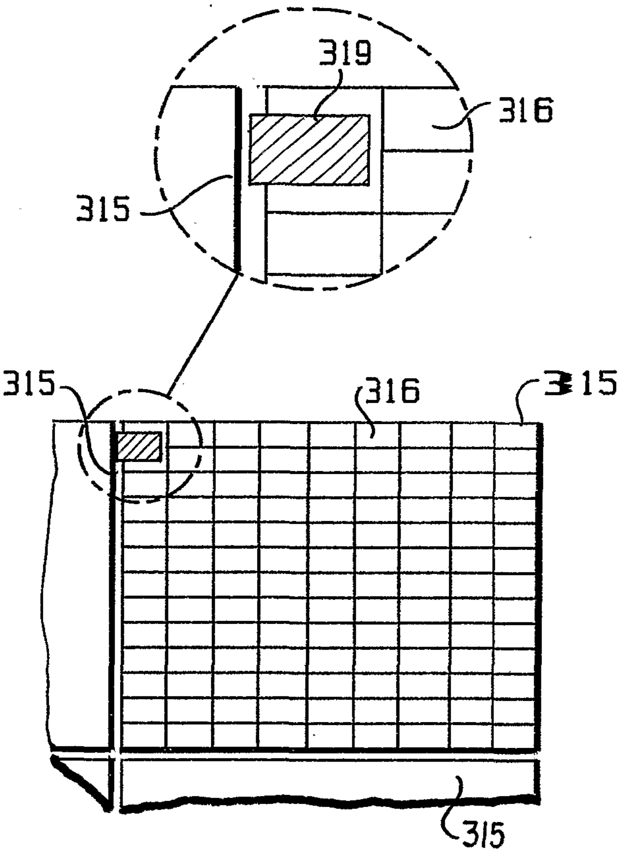


FIG. 3b

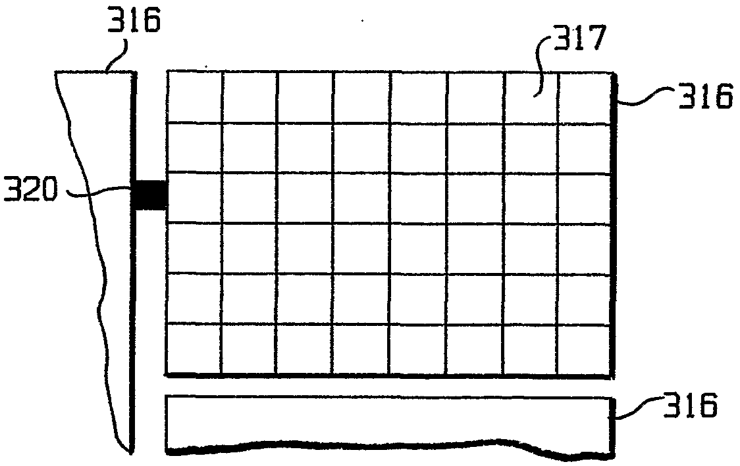


FIG. 3c

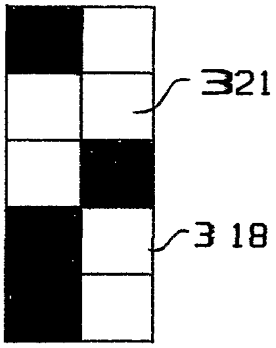


FIG. 3d

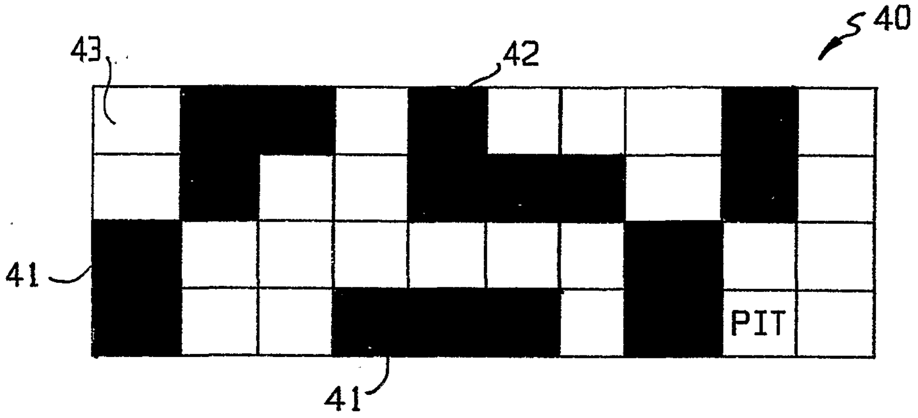

40
43
42
41
PIT
41

FIG. 4

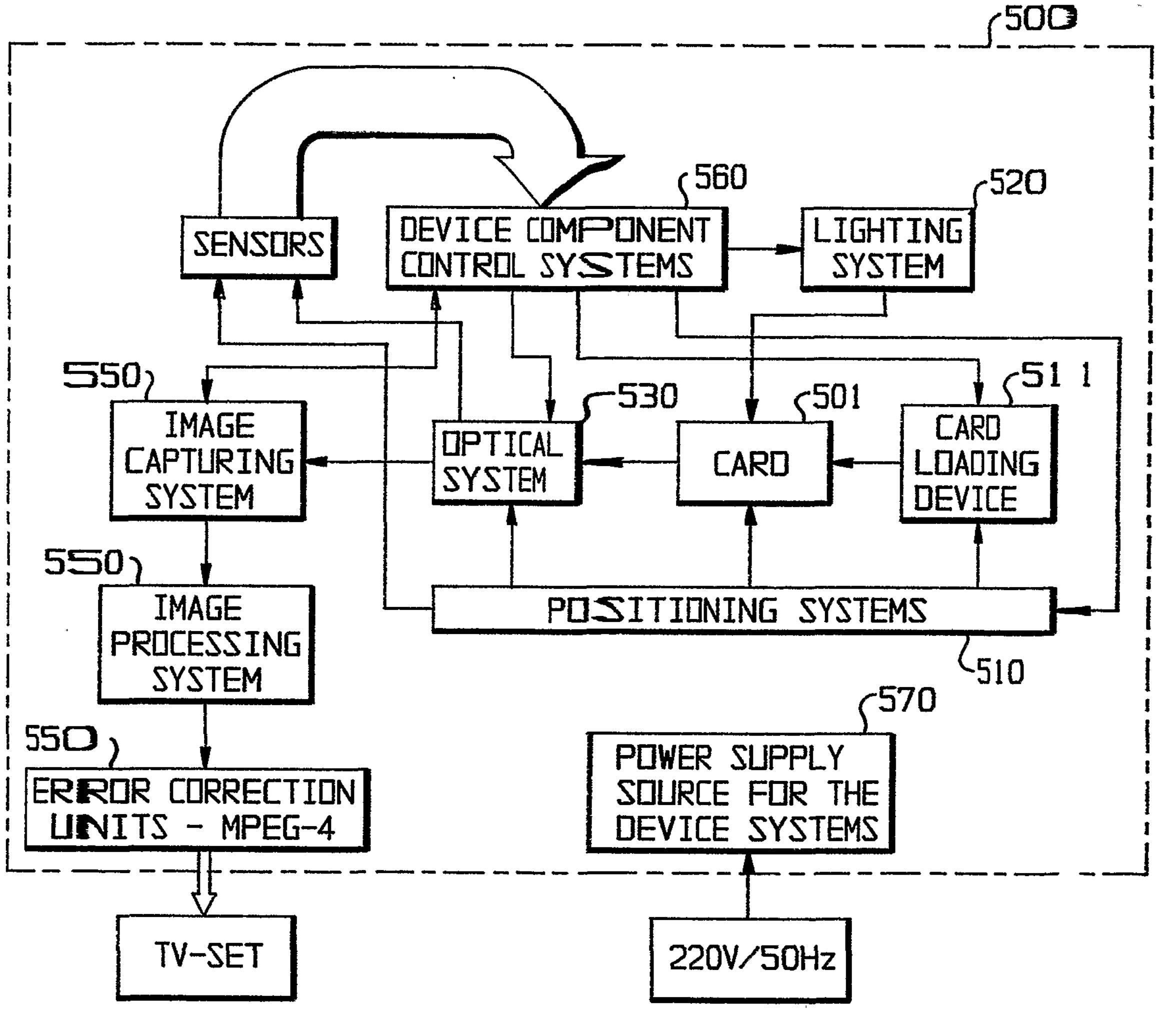

500
SENSORS
DEVICE COMPONENT CONTROL SYSTEMS
560
LIGHTING SYSTEM
520
550
IMAGE CAPTURING SYSTEM
OPTICAL SYSTEM
530
CARD
501
CARD LOADING DEVICE
511
550
IMAGE PROCESSING SYSTEM
POSITIONING SYSTEMS
510
570
550
ERROR CORRECTION UNITS - MPEG-4
POWER SUPPLY SOURCE FOR THE DEVICE SYSTEMS
TV-SET
220V/50Hz

FIG. 5

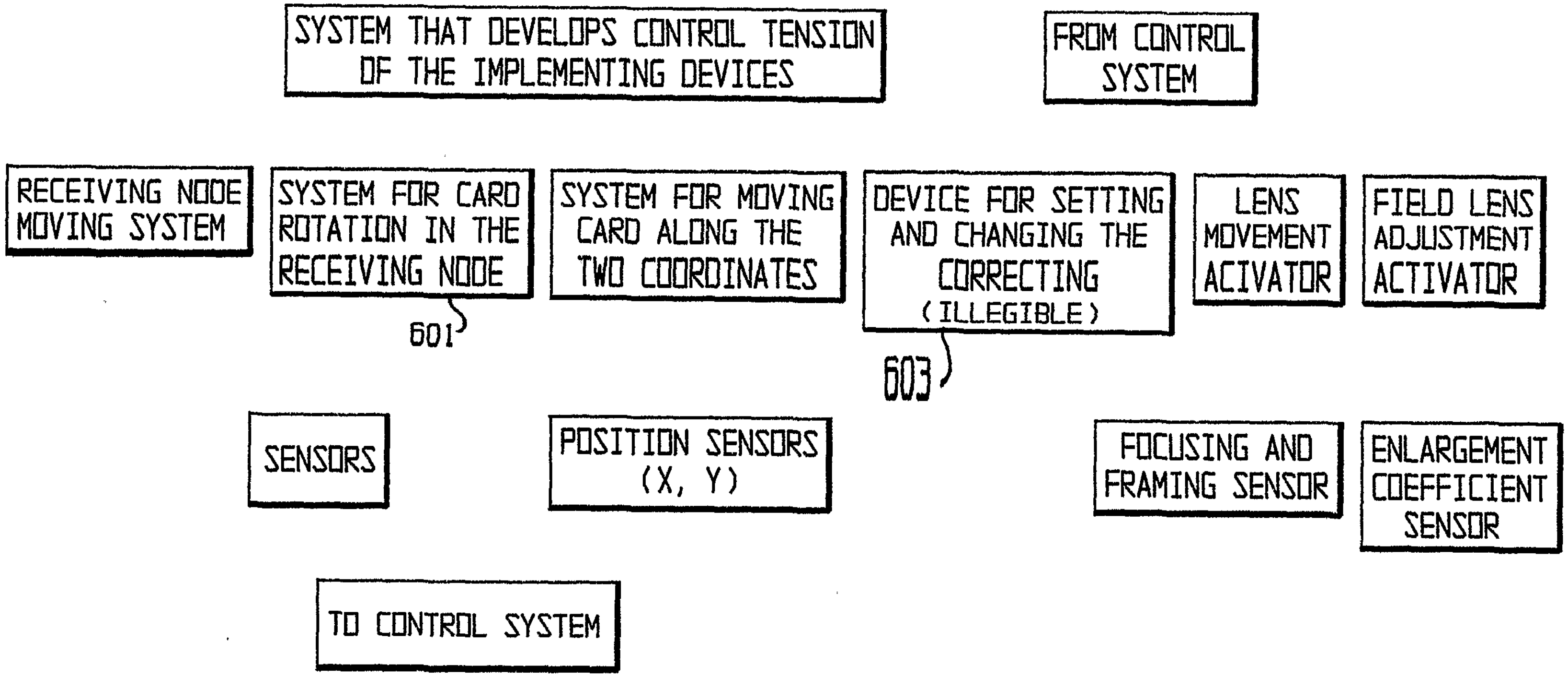


FIG. 6

POSITIONING MOVING SYSTEM

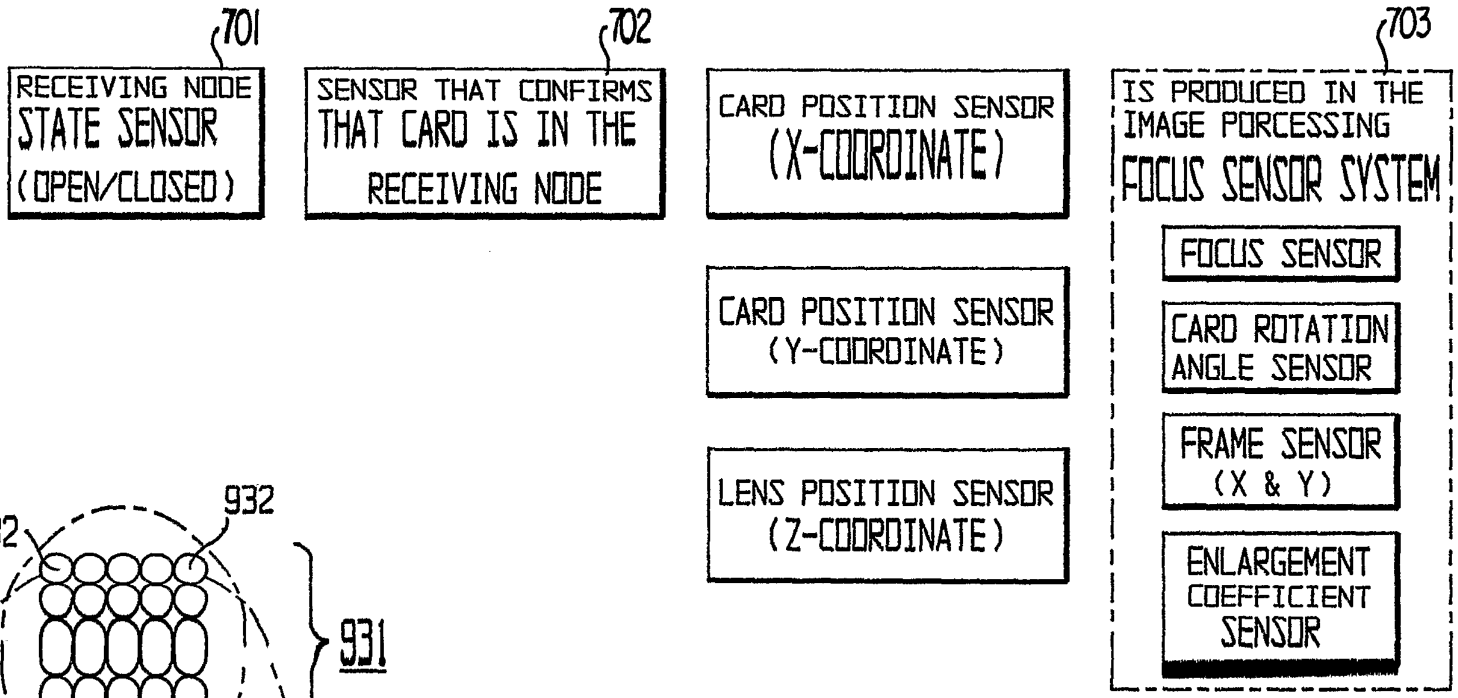

701
RECEIVING NODE
STATE SENSOR
(OPEN/CLOSED)
702
SENSOR THAT CONFIRMS
THAT CARD IS IN THE
RECEIVING NODE
CARD POSITION SENSOR
(X-COORDINATE)
CARD POSITION SENSOR
(Y-COORDINATE)
LENS POSITION SENSOR
(Z-COORDINATE)
703
IS PRODUCED IN THE
IMAGE PORCESSING
FOCUS SENSOR SYSTEM
FOCUS SENSOR
CARD ROTATION
ANGLE SENSOR
FRAME SENSOR
(X & Y)
ENLARGEMENT
COEFFICIENT
SENSOR

FIG. 7

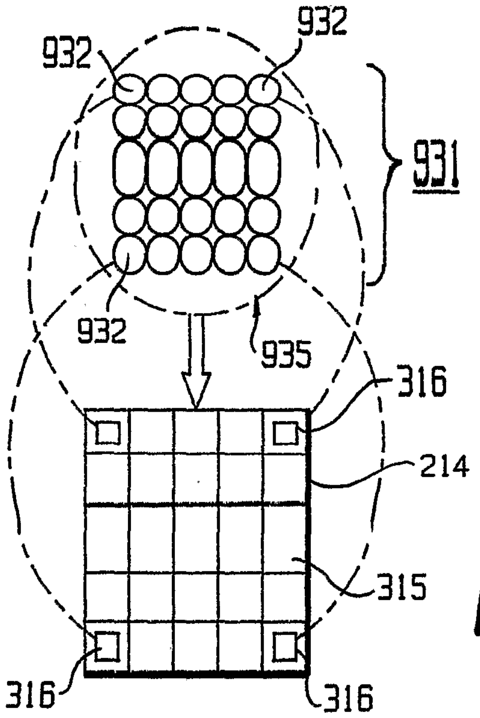

932
932
931
932
935
316
214
315
316
316

FIG. 11

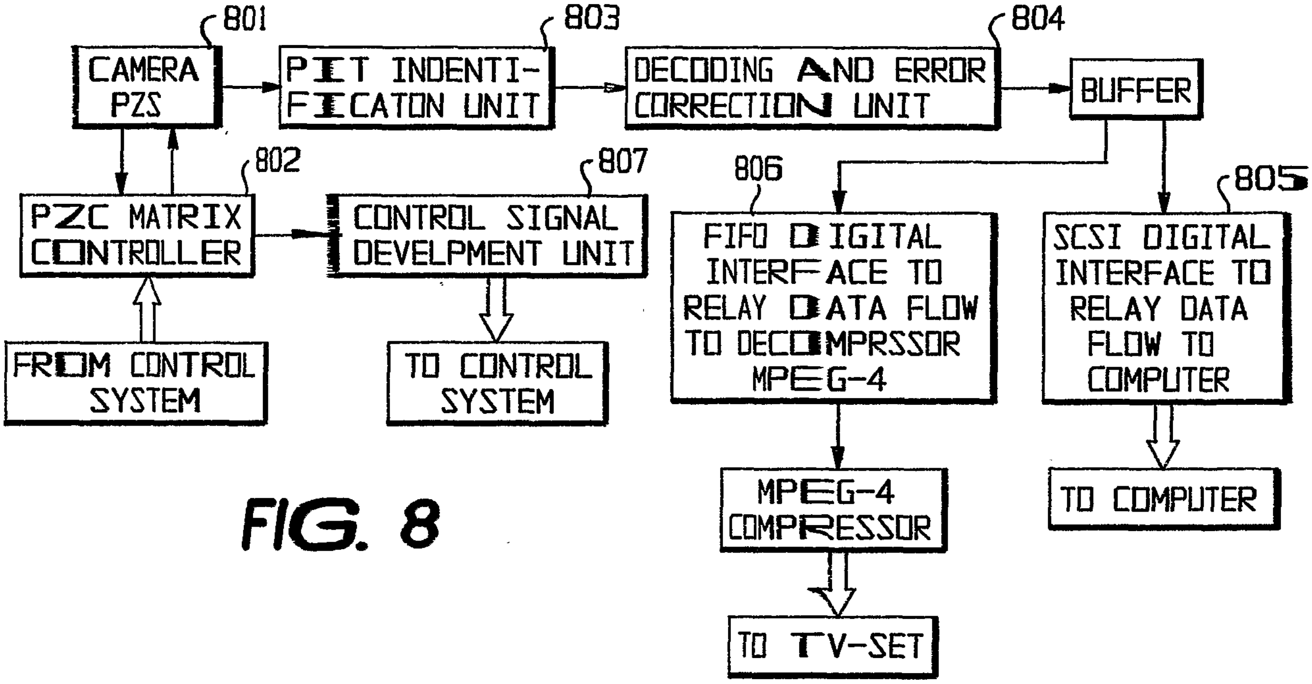

801
CAMERA PZS
803
PIT INDENTIFICATON UNIT
804
DECODING AND ERROR CORRECTION UNIT
BUFFER
802
PZC MATRIX CONTROLLER
807
CONTROL SIGNAL DEVELPMENT UNIT
806
FIFO DIGITAL INTERFACE TO RELAY DATA FLOW TO DECOMPRSSOR MPEG-4
805
SCSI DIGITAL INTERFACE TO RELAY DATA FLOW TO COMPUTER
FROM CONTROL SYSTEM
TO CONTROL SYSTEM
MPEG-4 COMPRESSOR
TO COMPUTER
TO TV-SET

FIG. 8

FIG. 9

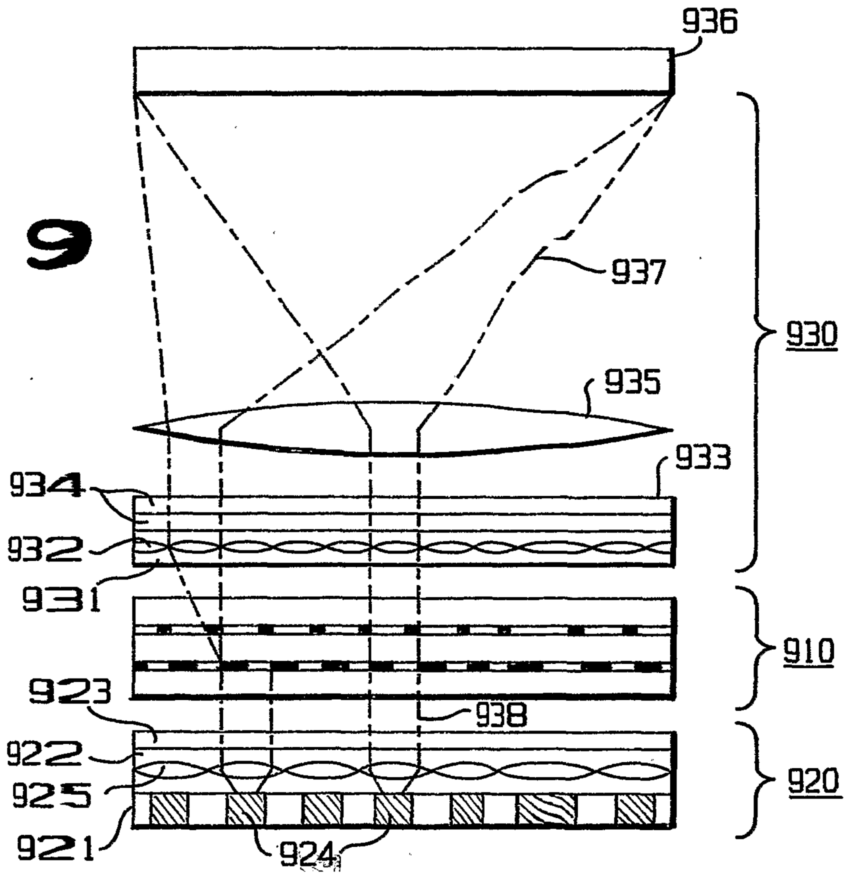

936
937
930
935
933
934
932
931
910
923
938
922
920
925
921
924

FIG. 10a

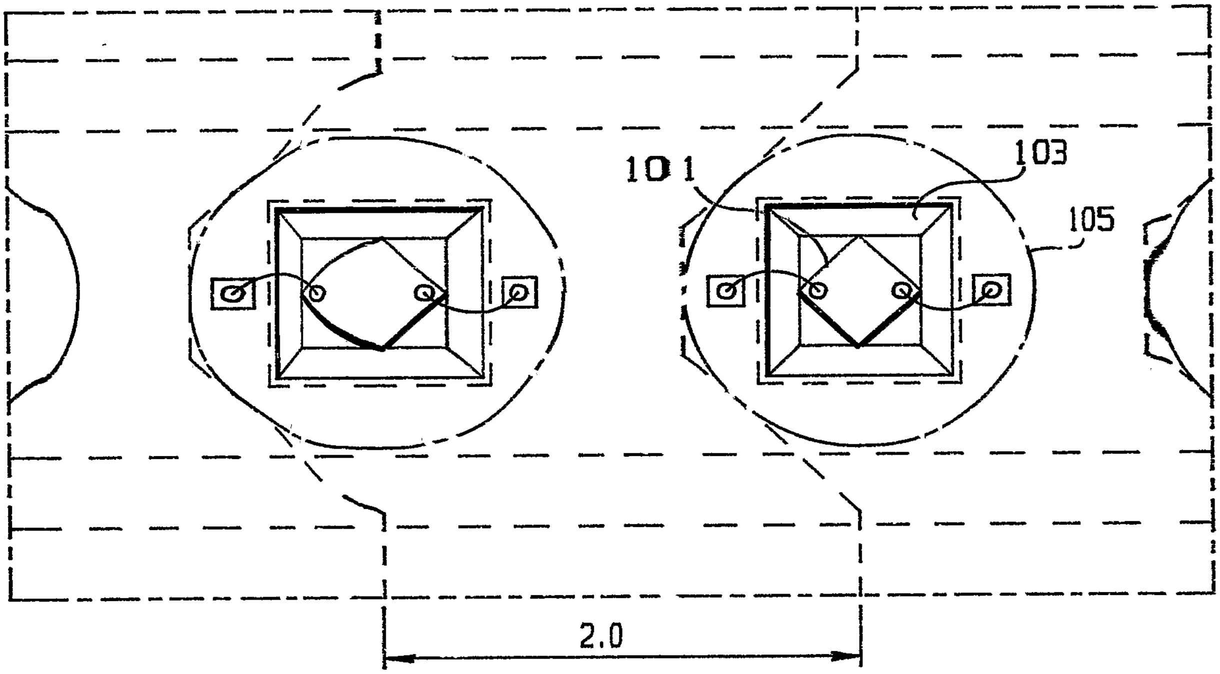
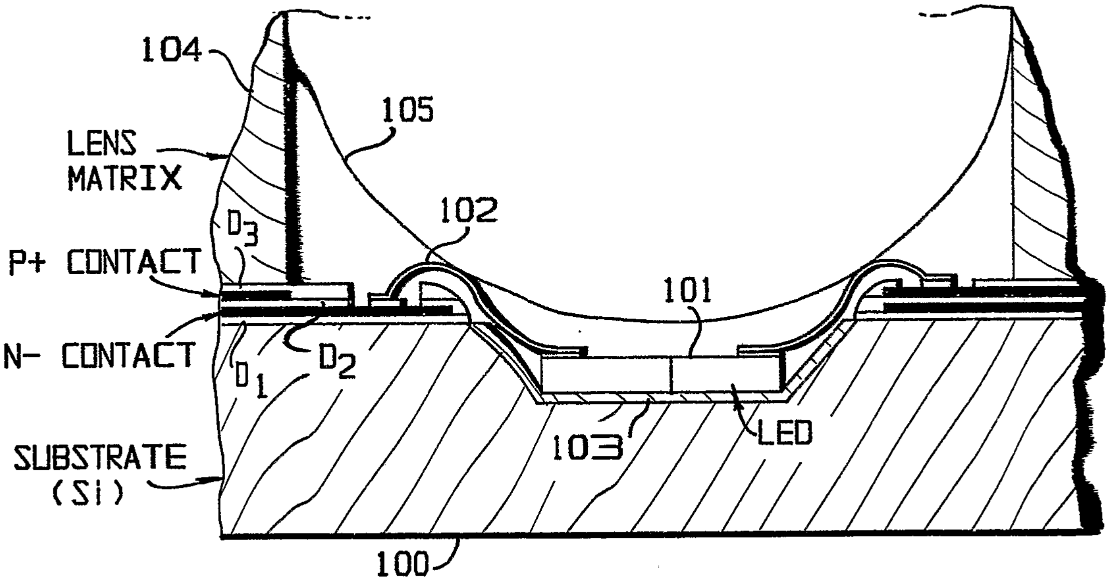


FIG. 10b



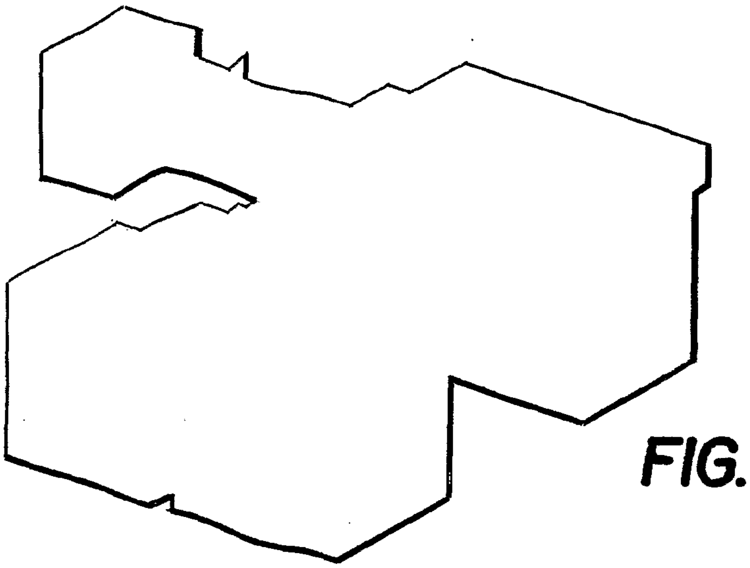


FIG. 12

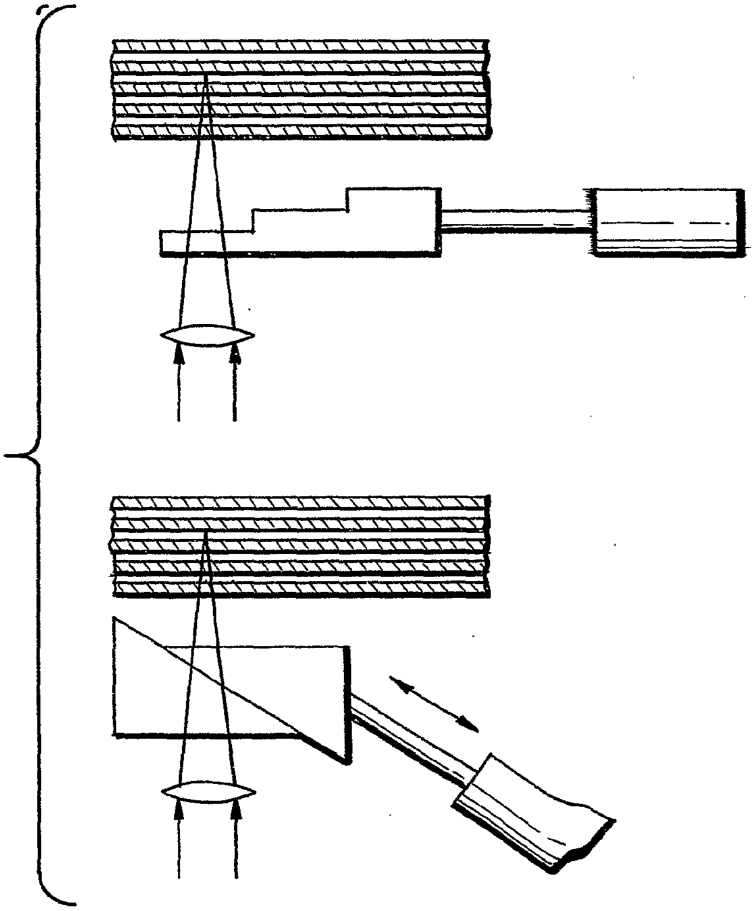


FIG. 13
(PRIOR ART)

FIG. 14

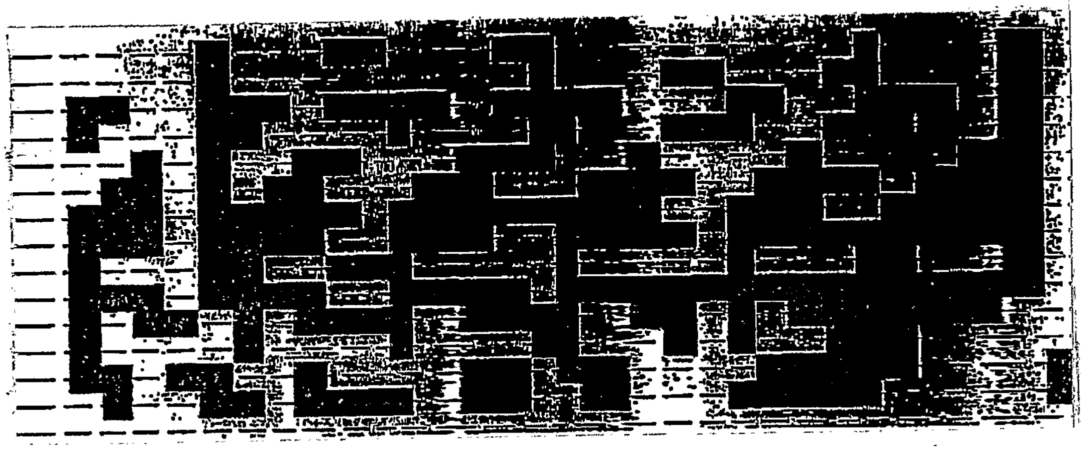


FIG. 15

FIG. 16